NPSAG RAPPORT 36-001:01

Workshop on handling of seismic events in Swedish PSA:s

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Nordiska PSA Gruppen (NPSAG) är samarbete för forskning och utveckling
inom PSA-relaterade frågor vid de nordiska kärnkraftverken

NPSAG:s verksamhet

NPSAG grundades i december 2000 av kärnkraftbolagen i Finland och Sverige. Strålsäkerhetsmyndigheten (SSM) deltar i NPSAG som observatör och medverkar också som finansiär i flera för SSM säkerhetsviktiga FoU-projekt. Avsikten med NPSAG är att utgöra ett gemensamt forum för diskussion av frågeställningar med bäring på probabilistiska säkerhetsanalyser (PSA) för nordiska kärnkraftverk och med fokus på behovet av forskning och utveckling bland de medverkande parterna.

NPSAG följer och diskuterar aktuella probabilistiska utmaningar nationellt och internationellt, liksom PSA-aktiviteter vid de medverkande kärnkraftbolagen. Gruppen initierar och koordinerar FoU-projekt och -aktiviteter och diskuterar hur resultaten kan utnyttjas på bästa sätt. NPSAG värnar om en effektiv erfarenhetsåterföring i de projekt som bedrivs och om en bred omvärldsanalys till nytta för hela branschen.

Under årens lopp har NPSAG:s internationella nätverk vuxit kraftigt, t.ex. inom BWROG, EU:s forskningsprogram och OECD/NEA i Paris. Detta är i linje med gruppens mål att bidra till internationell utveckling och samsyn på frågor rörande PSA och riskinformerade tillämpningar.

NPSAG activities

The Nordic PSA Group NPSAG was founded in December 2000 by the nuclear utilities in Finland and Sweden. In addition, the Swedish Radiation Safety Authority (SSM) participates as an observer, and also takes part in the funding of many of the projects. NPSAG is intended to be a common forum for discussion of issues related to probabilistic safety assessment (PSA) of nuclear power plants, with focus on research and development needs.

The group follows and discusses current issues related to PSA nationally and internationally, as well as PSA activities at the participating utilities. The group initiates and co-ordinates research and development activities and discusses how new knowledge shall be used.

Over the years, international contacts have increased, e.g., within BWROG, EU research projects, and OECD/NEA. This is in line with the group’s aim to create a common and lasting basis for the performance of PSA and for risk informed applications of PSA in Europe.

NPSAG Godkännande

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Omdöme:

Den allmäna uppfattningen är att Sverige är ett land med låg seismisk risk, men även om risken bedöms som låg bör detta verifieras med analyser av anläggningens motståndskraft mot jordbävning. Säkerhetsanalysen av svenska kärnkraftsverks motståndskraft mot jordbävning ska genomföras med en deterministisk analys, såsom SMA, då det passar bäst in i det svenska regelverket för tillståndshavare.

Genomfört arbete i projektet ger vägledning för hur jordbävning kan hanteras i PSA. Arbetet, som har genomförts i form av en workshop har klarställt att risken för jordbävning bör adresseras med PSA, men att det inte är en kritisk aktivitet då risken bedöms som låg. Projektets rekommendation är att riktlinjer för en förenklad analys av jordbävning med PSA bör tas fram med utgångspunkt från genomförda SMA analyser.

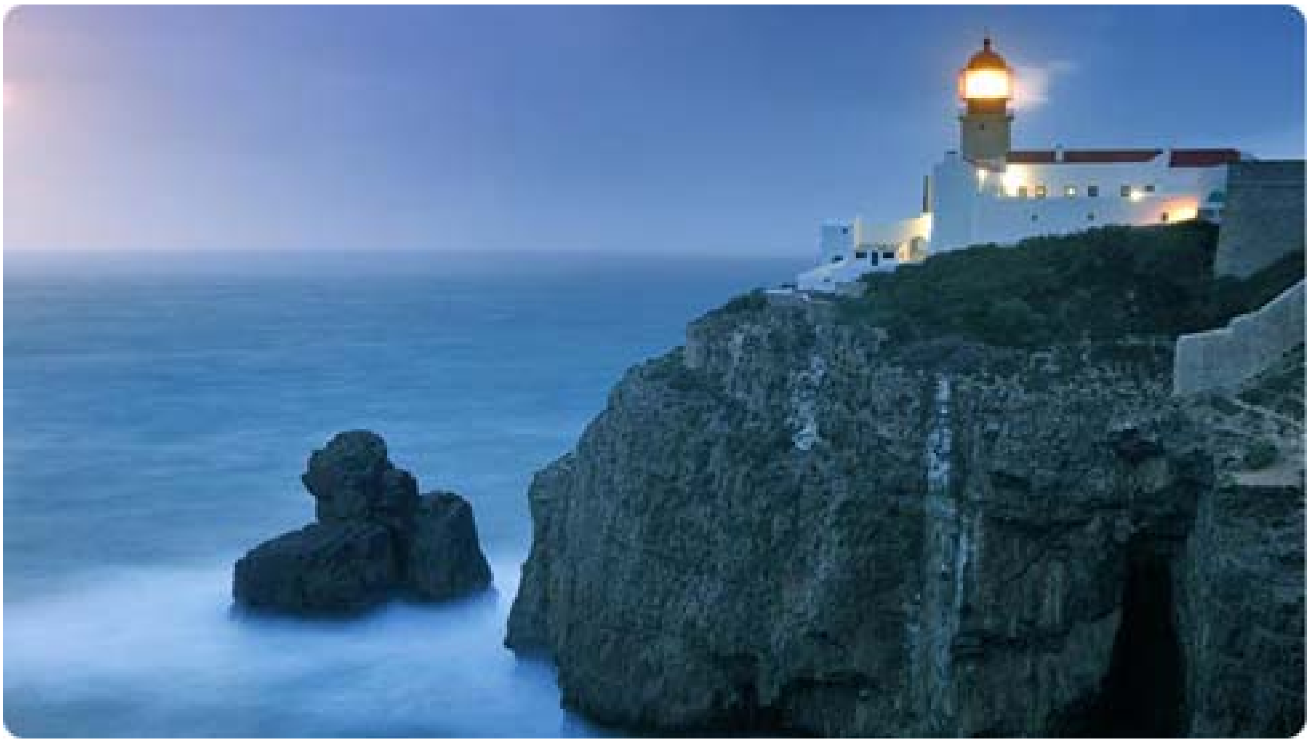
För att verifiera att responsspektrat för jordbävning i Sverige (Ski Technical Report 92:3. Summary Report. Characterization of seismic ground motions for probabilistic safety analyses of nuclear facilities in Sweden) ska SSM påbörja ett arbete med att se över analysen. Det är väsentligt att en sådan översyn sker regelbundet (ca 10 år) och att den inkluderar nya mätdata och nya kunskaper om hur man progonstiserar risker för kommande jordbävningar. Kraftindustrin kommer dock så länge SSM påbörjade studie pågår anse att rapporten från 1992 är representativ.

Signatur:

Stefan Eriksson, Ringhals AB

Report to NPSAG (RAB, FKA, OKG)

NPSAG Seminar on Seismic Risk Analysis



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Summary

NPSAG Seminar on Seismic Risk Analysis

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Executive summary

This report presents the NPSAG Seismic seminar on March 13-14 2013 at Arlanda airport. The report also outlines some suggestions for seismic risk analysis in Sweden.

Table of contents

Appendices

1 Introduction

A seismic workshop was hosted by NPSAG at Arlanda Airport March 13-14. The seminar was organized and facilitated, on behalf of the NPSAG, by Lloyd's Register consulting (Scandpower).

The aims of the seminar were to promote discussion about what type of seismic analysis it is reasonable to require for nuclear power facilities in Sweden.

Also, the seismic hazard curves – the Swedish spectra – should be put in perspective and the seminar should consider whether the spectra can be considered to be an appropriate representation of the seismic hazard.

The following organisations participated at the seminar:

- Fennovoima (future NPP)
- FKA (NPP)
- Fortum (NPP)
- KKL (NPP)
- OKG (NPP)
- RAB (NPP)
- Dr Ravi Ravindra (consultant)
- Risk Pilot (consultant)
- Scandpower (consultant)
- SSM (Authority)
- STUK (Authority)
- TVO (NPP)
- Professor Willy Aspinall (consultant)
- Uppsala University (university/consultant)
- Vattenfall (consultant/power producer)
- Westinghouse (NPP vendor)
- Yanev and associates (consultant)

A list of participants is found in Appendix 1.

It can be concluded that all NPPs in commercial operation in the Nordic countries were represented as well as the Swedish and Finnish nuclear regulators. Also, the participants represented a significant part of the Swedish and Finnish organisations performing PSA, but the representation was not limited to PSA competency.

The presenters at the seminar were:

- Göran Hultqvist, FKA (Introduction – setting the scene)
- Ravi Ravindra (Several presentations about seismic risk analysis)
- Björn Lund, Uppsala University (Earthquakes and seismic hazard in Sweden)
- Willy Aspinall, Aspinall & Associates (Site specific seismic hazard assessment…)
- Sam Swan/Andrew Yanev, Yanev Associates (Use of experience data in seismic qualification)
- Tim Courtney/Woody Epstein, Scandpower (Future development in seismic fragility)
- Pentti Varpasuo, Fortum (How Fortum has developed the seismic PSA)
- Olivier Nusbaumer, KKL (Development of Seismic PSA at Leibstadt NPP)
- Saikumar, B.V., Scandpower (Seismic PSA modelling)
- Jari Pesonen, TVO (Seismic PSA for OL1 and OL2)
- Janne Laitonen, STUK (The regulatory role of seismic PSA in Finland)

All presentations and the agenda are found in Appendix 2.

The seminar was arranged by NPSAG and the funding partners were:

- OKG
- RAB
- FKA

Through the report the term PSA is used. PSA and PRA are in this context meaning the same thing, but the presentations show the terminology used by the presenters.

2 Seminar

To facilitate discussions, a programme of presentations was developed covering technical aspects of seismic margins assessment (SMA) and seismic PSA. The seminar agenda is presented in Appendix 2, with presentations grouped into the following themes:

- Theme 0 – Setting the scene;
- Theme 1 – SMA versus seismic PSA;
- Theme 2 – Seismic hazard;
- Theme 3 – Seismic fragility;
- Theme 4 – Practical experience in seismic PSA modelling (lessons learned);
- Panel discussion.

2.1 Theme 0: Setting the scene

After a short introduction by Scandpower (Ola and Tim), Göran Hultqvist presented an overview of the NPSAG activities. Göran then continued with an overview of the current approach to demonstrating the capability to withstand an earthquake in Sweden.

Currently, there is no seismic PSA prepared in Sweden. For most types of initiators (except seismic), it is a requirement to include it in the PSA.

There is significant uncertainty about the hazard levels, since it is not possible to exactly define an earthquake which corresponds to a given return period. In addition, by design there is conservatism built into the component fragility. Therefore, if we develop seismic PSAs in Sweden, it would be preferable to use a common approach, definitions and practice when the seismic PSA is developed to have comparable studies.

The current seismic risk analysis is performed by SMA with the requirement that core damage shall be avoided (and safe shutdown shall be possible) at a 10^{-5}/yr event, and that the containment function shall be maintained for a 10^{-7}/yr event.

Only F3/O3 were designed for seismic events. The rest of the plants were not. However, all have performed, or will perform in the near future, seismic assessment of the buildings and piping. All plants have performed SMA using the SQUG GIP methodology for equipment qualification. All identified vulnerable equipment has been or will be upgraded to ensure capability to withstand the 10^{-5}/yr seismic hazard before the end of 2013. In addition, all plant modifications since the early 1990s have taken seismic loading into account.

The presentation ended with the formulation of the following goals for the seminar:

- Understand the uncertainty in the seismic spectra developed in 1980s;
- Understand ongoing activity;
- Understand the value of a seismic PSA for Swedish NPPs.

Göran’s presentation is found in Appendix A.

Comments:

There was discussion about the selection of a target (consistent with Finland) of 10^{-5}/yr for nuclear safety to be maintained. For comparison, the US, UK and Switzerland set a target of 10^{-4}/yr.

Another comment was that, for consistency during the calculation of ground motion, we should ensure that we adopt the same method for combining the different accelerations. Different methods for calculating seismic hazard will yield different results. The important issue here is to benchmark the Swedish hazard versus current seismicity and current probabilistic hazard assessment methodology.

It is noted that there is no internationally accepted single guideline for production of earthquake spectra for different probability levels. As discussed later in this report, the Swedish spectra should be reviewed periodically.

2.2 Theme 1: SMA versus seismic PSA

Ravi Ravindra. Presentation found in Appendix B.

Lots of commonality between the data used for seismic PSA and SMA. The choice of method has a historic basis in the availability of data and accuracy.

Seismic PSA - used when using PSA applications is required; estimates the contribution to risk from seismic hazard.

Two SMA methods were developed to answer the US NRC question about cliff-edge vulnerability to a defined level of earthquake (the review level earthquake (RLE)):

- EPRI SMA is used for the Swedish NPPs. It looks at the success path.
- NRC SMA is developed to handle cliff-edge effects. It is more like a seismic PSA. Does not look at success path, and is based on event trees and fault trees.

New plants are required to submit a PSA, but because insufficient information is known about the site, a seismic PSA is not required at the design stage. A PSA-based SMA may be used for a generic seismic assessment.

Ravi also presented the seismic PSA standards in different countries.

Seismic PSA and SMA were presented and differences were discussed. Both methods focus on the more vulnerable items to provide a limiting seismic capability (as opposed to a rigorous qualification of all of the plant required to withstand the earthquake).

Uncertainty of the seismic hazard is a very important input to the seismic PSA.

Using the fragility, we can define the HCLPF (High Confidence of a Low Probability of Failure) value for a component. It is taking into account that the design of the component includes several sources of conservatism, such as safety factors on loads and capacity, and load combinations.

Benefits and shortcomings of SMA

+

Easily adopted

Focus on a few important systems to bring the plant to a safe shutdown - "success paths"

Screen out a large number SSCs (as not vulnerable to the seismic hazard)

Calculation of HCLPF using CDFM method

Extensively used

-

Need agreement on review level earthquake (uses a single level of earthquake against which seismic margins are demonstrated)

Does not provide risk insights

Not endorsed US NRC for risk informed applications

Benefits and shortcomings of PSA

+

Makes use of site specific hazard analysis (the PSA uses the information from the whole range of seismic hazard)

Examines all important accident sequences

Screening and walkdown are done to minimize effort to represent realistic conditions of SSCs (again, as with SMA, screening out of SSCs that are judged as not vulnerable to the seismic hazard)

Fragility analysis of a subset of SSCs and risk quantification (this requires greater analysis effort than when calculating the HCLPF as in the SMA)

Provides risk metrics of CDF and LERF

Procedures, data and standards exists

-

Large uncertainties due mainly from seismic hazard

Need trained fragility analysts and specialized software

2.3 Theme 2: Seismic Hazard

2.3.1 Earthquakes and seismic hazard in Sweden

Björn Lund Uppsala University. Presentation found in Appendix C.

Björn presented the seismic activity in Sweden, showing that it is a low seismicity area. But there have been some earthquakes, the largest in 1904 with magnitude (M_L) 5.5 outside Kosteröarna. No larger than magnitude (M_L) 4.3 has been recorded the last 11 years.

The new recorded data compared to the old data for the Nordic countries has a good fit with the log of events versus magnitude relation.

Data for Japan was presented and compared with Swedish data on slide 18. The Swedish data is about 1000 times lower.

If the graph is extended, a magnitude 7 earthquake would be expected about once in 10,000 years.

There has been an extremely large earthquake in the Nordic region, the Pärvie event, with an estimated magnitude of 8.2 (M_L). However, this was caused by post-glacial rebound, where stresses were induced in the ground due to recovery of deformation caused by the overburden weight of glacial ice. The return period of an earthquake of similar magnitude to the Pärvie event is 1 million years, see slides 21 and 24. The recurrence of such an event is very uncertain and may require an ice age!

The presentation also gives an overview of the hazard frequency analysis and issues involved in that. The latest available seismic map is presented on slide 30. However, Björn stressed that this is a reflection of the recorded instrumental data (i.e. the hazard is artificially low because instrumented records have only been available since instruments were first installed in 1904). Björn commented that, on this basis it looks like the seismic risk for the Forsmark plant is almost zero – but it is not!

2.3.2 Site specific seismic hazard assessment for nuclear facilities in low seismicity regions

Willy Aspinall of Aspinall & Associates. Presentation in Appendix D.

Willy presented an analysis of an Armenian NPP. The presentation introduced the faults and the implication if a plant is located very near or on a fault.

Willy showed an estimated curve for an UK plant, and the actual data supporting that (page 9). Willy also stressed that there are huge and questionable uncertainties in the equations for creating the hazard curve.

The distribution presented on page 10 for the Armenian plant has a low uncertainty. This is due to the UK approach of not including all types of uncertainties. This was contrasted to the Pegasus project in Switzerland. The UK do not believe that this is the correct path to follow. *This is a controversial statement and shows that defining hazard curves are not necessarily in agreement worldwide! The UK approach is to use expert judgement at an early stage to limit uncertainty, whereas the approach adopted by the Pegasus project was to retain all uncertainty and rely on available computing power to deal with the resulting wide range of uncertainty on the hazard.*

Willy also stated that a 10^{-4}/yr event, in an area with no detected earthquakes would be approximately 0.08g peak ground acceleration (using the gamma distribution method as used in UK). Therefore it is questionable whether the Swedish spectra of 0.11g at a 10^{-5}/yr event are consistent with this (based on a 10^{-4}/year event having a PGA of 0.08g when there are no recorded earthquakes, a 10^{-5}/year event would be expected to be greater than 0.11g).

Willy presented some issues, e.g. how to combine different ground motions. There are 7 or 8 methods and they will produce different values for PGA. Hence, different methods produce different results and they are not comparable.

The UK is using a lower threshold than other parts of the world with regard to the minimum magnitude to analyse. The UK uses magnitude 4 (considered as a threshold for damage to plant) whereas the US uses magnitude 5 (considered as a threshold for damage to buildings and infrastructure). Variation in the minimum magnitude makes a significant difference to the results, whereas variation in the maximum magnitude does not. This should preferably be taken into account in the benchmark of the Swedish spectra.

The 10^{-6}/yr events with the estimate of the factors are, with Willy's words, really dodgy ("you are in muddy waters"). The uncertainty is really significant. With the 10^{-4}/yr events, this is not as sensitive.

Willy also presented the effect of selection of attenuation relationships (how the earthquake changes from its source to your site). As part of the decision there should be an evaluation of the impact of the choice of attenuation relationships. An example is provided in the presentation.

In addition, Willy also presented Zoneless methods for hazard source modelling.

A program called KERFRACT can be used.

2.3.3 Discussion

Are we any closer to answering the question "is the Swedish hazard appropriate?"

The question is whether 'out of the blue' events are covered by the Swedish spectra.

Prof. Aspinall's presentation showed that the Armenian hazard risk was performed 1993, 2004 and updated 2011 – and the Swedish curve was developed 1992. Is it relevant?

SSHAC method used in US with requirement to update hazard analysis – impact on Sweden?

2.4 Theme 3: Seismic fragility

2.4.1 History of development of seismic PSA

Ravi Ravindra. Presentation found in Appendix E.

The presentation shows the background to seismic PSA. Diablo Canyon is probably the best documented seismic PSA – still.

Latest development is that ASME/ANS RA-Sa-2009 Part 5 "Requirements for Seismic Events as Power PRA" addendum B in 2013.

Recently an NRC letter 50.54(f) Fukushima NTTF Action has been sent. It will require a lot of activity. Refer to NRC letter 50.54 for the required actions.

A conclusion from the US is that the industry has been fairly receptive to the use of seismic PSA. Seismic PSA is considered essential. The reason being that you are required to perform seismic PSA to be able to do risk-informed applications based on the PSA.

A SQUG walkdown will provide input to an SMA or a PSA with regard to equipment screening and qualification. There are courses held every 6 months for training engineers to do SQUG plant walkdowns etc. This is arranged by EPRI/NEI.

Reg Guide 1.208 is used as a method for treating the Fukushima event.

The seismic PSA is the preferred alternative (compared to EPRI SMA) for risk informed applications, new plant licensing and Fukushima NTTF actions.

2.4.2 Theory of fragility development for structures and equipment

Ravi Ravindra. Presentation found in Appendix F.

The presentation defines the term fragility and its interpretation. The failures (limit states) of structures, piping, equipment, soil failure modes and dams are discussed.

The fragility model is presented, see slide 7. The fragility is expressed as:

$A_m * \varepsilon_R * \varepsilon_U$, where A_m is the median capacity and ε_R and ε_U are lognormal variables.

The presentation also describes how to derive the A_m, see slide 9 (fragility model cont.).

The fragility estimate requires consideration of a number of factors to be able to estimate the capacity of the equipment, e.g. site characteristics, seismic response analysis, design criteria, failure criteria, dynamic response characteristics, etc. Also generic data like test data, past performance and fragility tests.

The presentation describes how to develop the seismic equipment list (SEL). A reduced set of initiators is typically used to define which systems should be evaluated. Initial screening is then performed using the tables in EPRI NP-6041, which show the generic capacities of SSCs provided that they satisfy some "caveats" (criteria which confirms the absence of features known to be vulnerable to earthquakes). The components with significantly higher seismic capacities are screened out. Then, for the equipment not being screened out, clearly define the failure modes prior to plant walkdown.

The site walkdown is used to confirm which failure modes will be limiting for each item of plant not screened out, including the potential for interactions between systems that could potentially pose significant problems (e.g. secondary damage hazards and spatial interactions). The role of the fire protection system should be considered, both in its ability to mitigate a seismically-induced fire (should this be considered credible) and also for either an inadvertent actuation or breach of the fire protection system.

The walkdown procedures are given in EPRI NP-6041 and NUREG-1407.

Some examples of seismic walkdown findings are presented in the presentation.

The civil structure analysis is presented with regard to assumptions. The major passive equipment items are also discussed, e.g. RPV, steam generator, reactor coolant pumps, recirculation pumps, pressurizer, etc.

For other passive equipment, generic fragilities are mostly used. Experience has shown that there is a tendency to be conservative when developing generic fragilities as opposed to plant specific fragilities.

For active components, more time is spent in developing fragilities. A combination of generic and plant specific data is normally required. Fragility testing of components has been conducted under the NRC funded research "Component Fragility Program" at Brookhaven National Laboratory (BNL) and Lawrence Livermore National Laboratory (LLNL). In the presentation some generic data are presented and also some examples on fragility. There are some fragility references in ASME PRA Standard part 5, NUREG/CR-5270, EPRI TR 103959 and there are published Seismic PSAs.

Note (this is added after the conference and not stated by Ravi): Development of a fragility curve would include performance of identical and similar equipment from previous earthquakes or from shake table testing. Where such experience data does not exist, the fragility curve would be derived from first principles (from design codes). Prior seismic qualification of equipment can provide information useful in the derivation of the fragility curve.

2.4.3 Use of experience data in seismic qualification

Sam Swan / Andrew Yanev, Yanev Associates. Presentation found in Appendix G.

The presentation covers the experience data collected from over 30 earthquakes. The data was collected from both nuclear and non-nuclear facilities, but contains equipment that is representative of that which is found at nuclear facilities.

The equipment is collated in about 25 groups, or ‘Equipment Classes’.

In the SQUG approach a Reference Spectrum is developed. The SQUG started in 1981.

A positive reflection from the Onagawa mission is that nuclear components can survive large earthquakes, particularly where they have been designed to withstand some level of earthquake.

A normal problem for active components is that the control logic stops (shuts down) the equipment to protect it and this might be interpreted as a seismically-induced failure because the system ceased to function. However, often the equipment is actually not damaged and only needs to be reset (but is unavailable until reset). This type of failure could be taken into account in the analysis, but it would require an operator action. To claim additional operator actions is however not necessarily the preferred alternative.

An example was provided on how fragility data can be derived from experience data. The method was also analysed with regard to sensitivity, and compared to data used in some studies.

The example of a crane illustrates factors that should be taken into consideration when the capacity of the crane is analysed. The building amplification is discussed. In addition to the building amplification, also the crane amplification needs to be taken into consideration (maybe a factor of 4-5 around the natural frequency of the equipment). Normally the amplification (guideline driven) is around 6, but from experience it is very likely to be lower.

2.4.4 Examples of fragility curves development in the US

Ravi Ravindra. Presentation found in Appendix H.

The most important reference is EPRI-TR 103959.

An example of a fragility analysis was presented. For a typical equipment item the failure modes are the structural integrity, the functionality, the equipment anchorage and interactions. It is for the fragility engineer to use the seismic walkdown to guide the development of a fragility curve to represent the vulnerability to each of these failure modes.

The equation for estimation of component fragility is presented and discussed. There are examples in TR 103959 that describe the process.

A simplified alternate approach (see slide 13) based on assumed CDFM HCLPF value is presented. Also assume the generic β_C=0.45. Am can then be calculated with the formula given, and the β_R=0.6 * βc and the β_U=0.8 * β_C (factors based on generic assumption). Using this approach, the delta going from SMA to PSA regarding fragility is very small.

Notice that anchorage is analysed separately from the equipment.

2.4.5 Future developments in seismic fragility

Tim Courtney, Woody Epstein. Presentation found in Appendix I.

The presentation discussed, on a high level, the difference between a deterministic evaluation and a probabilistic evaluation with regard to fragility.

It also presented the results from the Onagawa mission, which in short could be summarised as – the earthquake was (almost) bounded by the design spectra and, as expected, the plant responded remarkably well to the earthquake. This is a success story for earthquake design! The greater threat to the safety of the facility came from the tsunami which had caused some water ingress into safety-related areas.

Woody Epstein also presented a discussion about which measure to use to represent the hazard (e.g. cumulative absolute velocity, CAV instead of PGA). Several earthquakes were presented as acceleration time histories, acceleration response spectra and CAV. From the data presented it was not obvious which earthquake caused the most damage and disruption. The well-made point was that damage might not be well correlated to response spectra. CAV might provide a more reliable correlation, but it still isn’t perfect. One of the key findings from the Onagawa mission was that some consideration for seismic loading during design (or retrofit) gives great benefit in providing seismic capability. For example, the non safety-related equipment was not designed to withstand the same level of seismic hazard as the safety-related equipment but it still generally withstood the earthquake. This result is indicative of conservatism and unquantifiable margins available during design.

2.5 Theme 4: Practical experience in seismic PSA modelling

2.5.1 How Fortum has developed the seismic PSA

Pentti Varpasuo. Presentation is found in Appendix J. This presentation was given as an interlude during Theme 3.

Fortum is using the Fennoscandia seismic hazard data.

The presentation showed the method applied for hazard and also shows the recent hazard curves for Loviisa, Olkiluoto and Hahnikivi.

Varpasuo presented the method for building fragility analysis as well as component analysis. Also examples of β_R and β_U are included.

An overview of the most important components in the PSA is presented. The most important component with regard to seismic risk is the steam generator.

Questions:

What are, for Fortum, the benefits with doing a seismic PSA compared to SMA?

Findings of vulnerable equipment.

SMA is limited to assessing margins against a certain earthquake (the review level earthquake (RLE) - this is not the case in seismic PSA. In the seismic PSA also higher magnitudes are analysed. Thereby the knowledge that you gain is greater.

Is there a difference in the assumption with regard to Finnish hazard compared to Swedish, should we update the hazard risk in Sweden? *The forum did not answer this question. It is discussed further in section 3.*

Are they consistent – should they be?

Yes, the hazard ought to be consistent.

2.5.2 Development of seismic PSA at Leibstadt NPP

Olivier Nusbaumer. Presentation is found in Appendix K.

KKL is following SSHAC level 4 methodology regarding seismic hazard analysis (NUREG/CR-6372). The new hazard curve of 2004 is significantly higher. Both the design base accident was much higher (before ~0.2g pga, new ~0.35g pga) and also the frequencies for high PGAs were much higher (orders of magnitude).

The earthquakes are defined in two different types earthquakes, far-field and near-field earthquakes. Near site dominant peaks of 10Hz and distant being 3-6 Hz.

The presentation also discusses the discretization.

The fragility equation is presented in an understandable way.

The KKL model is a full scope model. There are more than 8000 components and 600 rooms. Following screening this was reduced to 800 radiological important components in 120 rooms. Dedicated databases were developed.

The buildings were analysed with an ANSYS finite element model. The SASSI code was used to analyse the soil-structure interaction. Building response spectra were developed for each floor level.

An example of fragility documentation is presented, as well as some examples of component fragilities modelled in RiskSpectrum software.

The discretisation is done in 13 intervals (per type of earthquake) = 26 intervals.

Lower peak ground acceleration 0.05g pga

Higher peak ground acceleration 1.25g pga

The screening level for a component was set to 3g (components with A_m >3g are considered not affected).

Non-seismic qualified components (or reviewed) are assumed to fail.

The total seismic CDF result for the plant is approximately 1.5E-6 (which is about 54% of the total results). Internal events only contribute about 11% of total results.

The plant fragility is presented as a CCDP versus PGA, called plant fragility. The graph on slide 23 shows that the risk is reasonably controlled below a threshold.

The information is also used to perform the EU stress tests of Shutdown Paths.

2.5.3 Seismic PSA modelling

Saikumar Bulusu. Presentation found in Appendix L.

Key references were presented.

The steps involved in seismic PSA modelling were presented.

The component list for seismic evaluation includes all components in the internal event PSA, but also structures that house the PSA components are added, e.g. buildings and structures that may affect the PSA components (as secondary damage hazards).

A huge number of components are identified - this list needs screening. The screening is discussed briefly. Relay chatter as a failure mode is discussed separately, due to its importance.

Following the screening, the components are grouped. The correlation between components was defined, see slide 12.

The inclusion of the fragilities into the fault trees was described. Some assumptions that made regarding relays, logic cards etc are presented on slide 15.

HRA data are affected by the seismic event. In accordance with KKL guidelines, a post seismic events approach is taken, in which a lower limit PGA is set (0.2g) where the HRA is assumed unaffected and an upper bound (0.6g) where the HRA is considered 1.0. A linear assumption made between these two points as shown on slide 17 for short term actions, and for long term actions the probability is assumed unaffected up to 0.6g and then considered 1.0. (These models constitute a significant problem for KKL.)

The treatment of initiating events was presented. The assumption is non-recoverable LOOP for all initiators following an earthquake (from the second lowest interval, i.e. above a specific PGA), and large LOCA is modelled as an event in the event tree assumed leading directly to core damage. Small or medium LOCAs are not considered in the analysis. Seismically-induced fire and flooding were also discussed, but during the walkdowns those events were screened out. For further information, see slides 19 and 20.

The building failures are included in the event trees or FTs. Example of effects was discussed.

It can be observed that seismic failure of structures dominates the seismic risk. Maintenance of some systems (the bunkered systems) in combination with failure of the auxiliary building is an interesting combination.

2.5.4 Seismic PSA for OL1/OL2 units – methods and results

Jari Pesonen. Presentation found in Appendix M.

The reason for selecting seismic PRA as the tool at TVO was discussed. The reason for SPSA (and not SMA) was that this was considered a better tool for risk informed decision making.

The first version of the seismic PSA was launched 1997, with the latest update taking place in 2008.

The reasons for the update and the main activities in the update were discussed. The hazard risk was updated 2003. FENCAT was used as basis but there are no strong motion acceleration records found. These types of events are sought for in other similar regions. See slide 8.

In addition to the hazard, the ground response spectra were presented.

The equipment list needed only a minor revision in the update. About 800 components were in the SEL.

The plant walkdown in 1997 concluded that the plant was generally adequate to withstand an earthquake, but there are a few vulnerabilities or sources of spatial interaction – which carry potentially significant risk. A limited walkdown was performed 2008, with the conclusion that the plant was in a similar but improved condition as compared to the observations 1997. Most of the identified vulnerabilities had been rectified, but there were still some upgrades that was had not been performed (batteries).

A screening level of 0.3g HCPLF was established as an adequate screening level. With >0.3g as HCPLF the contribution would be less than 1E-9 based on the hazard curve.

HRA data are based on the ASEP program. Special attention was given to misleading indications. Available time for operator actions was studied, with e.g. MELCOR.

The EQESRA tool was used in both 1997 and 2008. The core damage sequences are then transferred to FinPSA.

The total CDF result at TVO is 1.35E-5 /year, of which seismic events are about 1%. The point estimate of seismic risk is 1.7E-7 /year. The CDF has been reduced since 1997.

The median capacity of the plant is 0.35g pga. The HCPLF value of the plant is about 0.12g.

The dominant seismic contributors are due to relay chatter.

SPSA has been effective means to pinpoint the weak points at OL1/2 units based on probabilistic reasoning. In discussion, the point was raised that a review of a deterministic assessment (such as SMA) would also identify the weak points (i.e. those with the lowest margins, taking into consideration the degree of conservatism in the assessment).

2.5.5 The regulatory role of seismic PSA in Finland

Janne Laitonen. Presentation found in Appendix N.

It can be noted that in Finland there are no requirements for seismic design of any structure with the exception of the one from STUK regarding nuclear installations.

The verification of the seismic analysis is performed through seismic PSA, full scope. YVL 2.8 states the requirements on PSA and YVL 2.6 is analysis of seismic events. The guidelines will be renamed, see slide 5.

Full scope PSA is required, including seismic analysis and other external events. The PSA shall be living.

The CDF objective is that it should be below 1E-5 and the radioactive release more than 100 TBq CS-137 should be below 5E-7.

The regulatory requirements are summarised on slides 5-9. Classification is divided in S1 (function required during/after earthquake) and S2 (function not required).

There are requirements that the buildings shall be founded in hard bedrock, because good foundation requirements decrease uncertainty in the estimate of the design basis earthquake.

The earthquake resistance is demonstrated through different analyses, and the overall acceptability is through seismic PSA.

The PGA values were updated in 2009 for southern Finland. The calculated values are, for TVO 0.085g and for Loviisa 0.056g. There is on-going analysis for determining the PGA for Fennovoima.

Loviisa key findings (low total results):

Dominant combinations:

- Failure of steam generators 54% HCPLF 0.06g
- Failure of feed water tanks 32% HCLPF 0.1g

Actions have been taken to reduce risk.

Olkiluoto 1/2 key findings (low results):

Dominant sequence:

- Spurious ATWS and isolation signals, HCPLF of the relay chatter is 0.05g

Actions have been taken to reduce risk.

Olkiluoto 3

Very low seismic risk.

The HCPLF on plant level is 0.1-0.14 for Loviisa, 0.12 for Olk 1,2 and >0.2 for Olk 3.

STUK's response to Fukushima is discussed on slide 16. There are no immediate actions required. Analysis of pool structures has recently been presented. Seismic fragility of the fire water systems is being investigated.

2.6 Theme 5: Panel session

Ravi Ravindra began the session with a few slides, presented in Appendix O.

Below are the questions that were discussed during the panel session, with the background understanding that Sweden is in an area of low seismicity.

Do we need to revisit the hazard curve? When?

- What evidence do we need to support that decision?

Considering that the data is old it seems reasonable to review the data. Especially the zonations.

The curve is about 20 years old, therefore it could be about time to review it with consideration of about 20 years of additional instrumented data and developments to both attenuation relationships and the probabilistic seismic hazard assessment methodology.

SSM agreed with the ENSREG's recommendations to reconsider the existing seismic approach by taking into account the geodetic and paleoseismologic data. SSM intends to start a project for this purpose.

How often is a reasonable time frame to revisit the hazard spectra?

Periodic Safety Review (PSR) is carried out at regular intervals, typically every ten years. It would be expected that the on-going validity of the seismic hazard would be reviewed as a part of the PSR. In Sweden, the seismic hazard is presented in a SKI report and is effectively 'owned' by the regulator. Therefore, at their facility PSRs, the utilities would simply confirm that the SKI report remains current and hence it is necessary that the seismic hazard is reviewed at a similar frequency to the PSRs.

From a seismological perspective, 10 years is a short period with very little change expected in term of earthquake frequency.

Plant specific hazard spectra?

The seismicity in Sweden is fairly uniform where the plants are situated, so no significant differences are expected between sites.

As part of the review that is on-going (by SSM), the review should cover the methodology and whether or not site specific data is needed (as opposed to use of a single generic spectrum).

We have SMAs in Sweden. Do we need a seismic PSA? Benefits?

When an SMA is performed, it will identify the obvious weaknesses for the design basis earthquake (DBE), i.e. those structures and equipment that cannot be shown to withstand the

DBE. In addition, the assessment results will give an indication of the margin available beyond a target level of earthquake. However, an SMA does not provide as much insight into the contribution of earthquake hazard to the overall risk profile for different levels of earthquake. If you are not interested in those results, the need for a seismic PSA is regulatory driven.

The cost for the development of the PSA, given that you have the SMA, is not very big (the delta cost is small). Ravi Ravindra anticipated the additional cost to be in the range of 15-20% of the total cost for a seismic analysis.

Statement by Ravi Ravindra: "The need for a seismic PSA is regulatory driven, the cost is determinstic, the result is probabilistic and the impact is uncertain. The impact is uncertain, since you do not actually know the results."

The main objective with the SPSA is the insights, not the numbers.

Comment: The main insights from any seismic analysis are gained from the walkdowns, and this is the real benefit of the analysis. Walkdowns are a part of any seismic assessment (deterministic, SMA, seismic PSA).

Should we develop a seismic PSA in Sweden? It is also related to other important issues that should be included. Is external events PSA instead of seismic PSA (since there is already existing SMA) more relevant?

SSM position: The recent interpretation does not state that you are required to do a SPSA or SMA, no specific method is proposed. However, discussions within WENRA may require seismic PSA in the Swedish regulations.

To what extent do we need to assess the safety margins? How?

NRC requires a seismic margin of 1.667 of certified seismic design spectra. This can be shown by both SPSA and SMA.

3 Conclusions and discussion

Sweden is in an area of low seismicity. The earlier Swedish reactors were not designed or built with seismic hazard in mind and only the later reactor designs gave consideration to threat that an earthquake may pose to nuclear safety.

Seismic ground motions for Swedish nuclear facilities were developed in the 1990s and subsequently a significant programme of work has been undertaken to demonstrate the capability of all facilities to withstand earthquake loading.

The workshop was requested specifically to address the following:

- Review the credibility of the earthquake spectra that have been used for assessment of the Swedish reactor plant;
- Clarify knowledge of the effects of earthquakes, including margins;
- Compare alternative methods of seismic assessment and in particular to compare the merits of seismic margins assessment with seismic PSA.

3.1 Seismic PSA or SMA?

The real gain from performing a seismic risk analysis is to perform the seismic walkdown of the plant – and to find the potential vulnerabilities. The absolute values calculated during the analysis are subject to uncertainty, but that is not the main objective of the analysis.

The vulnerabilities can be evaluated basically by two methods (in reality there are of course variants of the methods available):

- A more "deterministic approach", SMA (seismic margin assessment)
- A probabilistic approach, SPSA (seismic probabilistic safety assessment)

The advantages with the methods are discussed in Section 2.2, but can be summarised by:

- The SMA is easier to adopt and the influence by probabilistic numbers are limited. The method will provide a "yes" or "no" to whether the requirements are met (deterministic) and will give an insight into the margins available for each component / system.
- The SPSA is more extensive and it gives a probabilistic result, no clear "yes" or "no". It also includes the potential effect of failures other than those that are seismically-induced. The SPSA provides means for risk ranking and risk information.

Both methods will identify the most important potential shortfalls.

The benefit of seismic PSA is potentially greatest for existing facilities that have not been designed to withstand an earthquake. In these cases, it is less likely that there will be significant excess capacity for all of the structures and equipment to cater for seismic loading. Seismic hazard can in such cases potentially contribute significantly to the overall risk at the facility and this can be estimated using seismic PSA (within the accuracy of the estimation of the hazard and fragility data). In cases where an SMA has been performed and outliers have been addressed, it is likely that seismic is a small contributor to the overall CDF.

For a facility that has been seismically designed, the seismic capacity of the structures and equipment should contain a reasonable margin above the predicted seismic loading and thus the benefit of the seismic PSA is limited to: appreciating the potential accident sequences; confirming adequacy of the deterministic basis for design and quantifying the contribution of seismic hazard to the overall risk.

In comparison to the Swedish way of performing the safety analysis, there is always a requirement to demonstrate the safety based on deterministic basis. Since SMA will give a clear "yes" or "no" answer to whether or not the plants meets the criteria – this is clearly easier to understand and to embrace for the plant management and the authority. This aspect shall not be underestimated.

The seismic PSA will give a risk ranking of the most important components and will help to risk inform the results and implementation. The uncertainties involved in a seismic risk analysis must however be understood. It is not reasonable to only make decisions based on the mean risk curve, but also the uncertainty has to be understood (Fukushima would be a good example of this).

Currently we do not have the framework in Sweden in place for decision making based only on seismic PSA.

Therefore, a deterministic approach should be the preferred choice as the acceptance basis with regard to seismic qualification.

Does this mean that we should not perform a SPSA? The question could be put as "why do we do PSA at all"? The purpose of performing a PSA is to, with the knowledge of that the plant design has been accepted from a deterministic stand point, calculate the risk of the plant to see if there are potential areas that should be focused from a plant risk perspective. The PSA also gives means to risk inform decisions and improvements of the plant. To be able to use the PSA as a basis for such decisions it should cover the risk dominant events.

If the PSA did not address seismic risk at all, and we do not know whether this is a significant contributor, what do the results from the PSA mean? The SPSA should very likely be a small contributor to risk and hence, given that there is an SMA, the SPSA could be very limited in scope and only focusing on confirming that the seismic risk is insignificant. Then the PSA would be covering also seismic events (if only limited) and the risk informed principle still holds.

To conclude:

The demonstration of the seismic capability should preferably be through a "deterministic" assessment such as SMA to produce a clear confirmation of the seismic capability of structures and equipment. This requirement should be met at all plants in a short time frame (if not already met).

Walkdown based verification methods which draw on experience of the seismic (structural and functional) performance of similar equipment are an effective means not only to detect seismic insufficiencies but also to verify seismic adequacy in a quick and economic way. Walkdown based methods are particularly economically effective for the seismic qualification of equipment installed at existing nuclear facilities, where it is often impractical to remove or duplicate equipment to be used for shake table testing.

The PSA should preferably include also seismic events, but this is not a critical activity (it can be aligned with the normal development of PSA scope). The PSA results (seismic contribution to CDF) should be low and thereby a conservative (and simplified) approach, as discussed during the seminar, could be used.

A simplified implementation of seismic hazard in the PSA would preferably make use of the SMA evaluation already performed. There are some alternative approaches that could be used, e.g. only consider the components that are below their HCLPF limit as available, or to convert the HCLPF to a fragility estimate using standard assumptions of the uncertainty parameters. The simplified method will need to analyse a range of PGA, and not only one threshold.

The large uncertainties in a seismic evaluation must always be considered, and a seismic PSA evaluation will therefore likely need some post-evaluation of the results by both the PSA analyst and seismic engineer.

3.2 The hazard, the Swedish spectra

The Swedish spectra should be reviewed with a view to confirming (or otherwise) that the hazard remains an appropriate representation of earthquake hazard in Sweden.

As part of the review, a discussion should be started with the Finnish practitioners to ensure consistency of approach. It would make sense if the same type of assumptions would be used in both countries.

SSM will start a review of the spectra and these questions will be addressed within that review.

At a later stage it would probably be reasonable if the responsibility for the spectra was not on the authority, but on the plants. The spectra should be up for a review approximately every 10 years.